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DIRECTED BLAST STUDIES (U)

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INTRODUCTION

Much of the work on directed, or focused, blast is done using large charges fired in open air. In general, the instrumentation for these shots does not provide adequate data for detailed analysis and the cost of making the shots is relatively high. Much can be learned at less cost by using scaled-down charges fired and observed under laboratory conditions. (It is assumed that the necessary firing chambers and the instrumentation already exist.)

At NOL White Oak we recently began such a study on small (< 1 lb) charges. We believe that our results can be scaled reasonably well to those that would be obtained with charges of warhead size. Our observations are made of the explosion product gas flow and the associated shock waves out to distances scaled to be equivalent to 30 ft. or more from a 100-lb charge.

Among the things we would like to obtain from laboratory experiments on small charges are:

1) The air shock velocity as a function of time or distance;

2) The velocity of the front of the detonation product gases;

3) The distance the gas front travels out from the initial charge position before stagnation occurs;

4) The pressure vs time history in the product gases as well as behind the air shock front;

5) The energy in the shock wave as a function of distance;

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6) The energy in the moving gases;

7) The damage to moving, as well as stationary targets, as a function of time; and

8) Comparable data at low ambient pressure, i.e., high altitude simulation.

Our own work to date, covers only Item 1, 2, and 3.

Much of what is reported here is not new in essence. For example, it is well known that the product gases tend to expand in a direction that is normal to the charge surface. It also is well known that the collision of detonation waves will cause a substantial increase in gas velocity in certain directions. We feel that the important contribution of the investigation is in making a detailed observation and qualitative analysis of the motion of the gas envelope and of the air shock ahead.

Some results are given here on solid cylinders and square geometrical prisms, single - and multiple - point initiated. Obviously, more data are required to confirm the results and complete the picture. A centrally initiated, 50-g sphere also was fired to see how well the results would scale to the work of others using much larger charges.

THE EXPLOSIVE CHARGES

The weight of the charges used in this study was, of necessity, restricted to an approximate range of 50 to 450 g. Our bombproof dimensions (9 1/2 x 17 x 8 1/2 feet) impose the upper weight limit, while the lower limit is set by the relative size of the detonators as compared to the charge and the run distance to full detonation after the detonators fire.

The initial charge geometry was chosen to be a cylinder with a length to diameter ratio of 1.5. This is somewhat typical of the shape of a simple type warhead charge. From this we want to square prisms of essentially equivalent weight.

The various charge systems, excluding the sphere, are shown in Fig. 1. The cylinders, 50.8 mm diam x 76.2 mm long, were of pressed Comp B-3 and weighed 257 g. The square prisms, 45.1 x 45.1 x 76.2 mm, were of cast pentolite and weighed 261 g. The detonator positions are represented by the x's. The detonators, Type SE-1, were mounted normal to the flat end surfaces of the charge. When properly energized, these detonators will fire within ±0.03 μsec of each other.

In all of the multi-point-initialed systems shown, the detonators were fired simultaneously. This was done for simplicity in the 6-detonator system and the results are not necessarily optimum. The arrows indicate the principal direction of velocity measurement. Note that for the 1-point cylinder and square prism the motion of the product gas front is at a small downward angle from the normal.

The small sphere of pressed pentolite was initiated at its center by a small, Ex-7 type, detonator. The diameter of the charge was 40.1 mm and its weight, exclusive of detonator, was 50.1 g.

EXPERIMENTAL APPROACH

Our experimental observations were made with the Jacobs focal plane shutter framing camera and a B & W Model 189 framing camera. The Jacobs camera is especially suited for this study. It takes up to 216 frames, using two 70-mm film tracks. Three rows of 36 (18 x 24 mm) pictures are obtained in each track. The maximum framing rate is ~ 10^6 f/sec. At a given framing rate, the exposure can be adjusted (each track independently of the other) from 0.005 to 0.16 times the time required to write one frame. The large number of frames leads to detailed plots of gas or shock position as a function of time. The B & W 189 camera was largely used to augment the data, because of its relatively small number (25) of available frames.

Because of the limited space in the firing chambers and the limited field of view of the cameras, the observations were made over three ranges: a) in the region immediately surrounding the charge, b) at about six feet from the charge, and c) at some intermediate position. For a), self-luminosity, and sometimes backlighting, was used. For b) and c), backlighting was necessary to record the shock and product-gas fronts.

In many shots, a simple switch, closed by the arrival of the shock front was located just beyond the edge of the field covered by the camera. The switch consisted of a sheet of Mylar film, aluminized on one side, and a bare, straight wire spaced a few millimeters away from the aluminized surface. The time of arrival of the shock at the switch was recorded by an oscilloscope. In later shots, an electronic timer also was used. The data obtained from switches extended the range of useful data and, therefore, were included in the x-t plots.

EXPERIMENTAL RESULTS

The position and shape of the cloud of expansion products and the associated air shock were obtained from framing-camera sequences. In Fig. 2 the outline of the gas front is sketched for a one-point-initiated cylinder. (Actually, the leading edge of the gaseous products of explosion and the air shock ahead effectively are recorded as a single front at such close distances.) In Figs. 3 and 4 are the outlines for 2-point and 6-point cylinders, respectively. Results for every sixth frame, i.e. 6.53 μsec intervals, are given for all three examples.

Fig. 5 is an example of a distance-time plot for a 4-point cylinder derived from the data, including those from switches. Note that at an intermediate position, 1200 to 1350 mm, definite separation of the air shock from the explosion gases occured. At a distance of 1700-1900 mm, only the air shock was observed.

Fig. 6 is an x-t plot of a 50-g pressed pentolite sphere. In the example, the gases are seen to stagnate at a distance of 430 mm and about 500 msec after detonation.

If the instantaneous velocity taken from an x-t graph is plotted as a function of $x^{1/3}$, a nearly straight-line fit is obtained for the 1-point sphere and the variously initiated cylinders, Fig. 7. The initial and close-in velocities are omitted in making the fit, since the errors are large in measuring the corresponding slopes. Although the data are not complete for the 1- and 2-point cylinders, an extrapolation can be made to the point at which stagnation occurs, i.e. zero velocity. No extrapolation is needed for the 50-g sphere, since stagnation actually was observed. The curve for the sphere, though, was scaled up (factor = $257^{1/3} / 50^{1/3}$ = 1.73) for the comparison. Although the gas from the 4-pt cylinder starts with the highest velocity, over the linear (drawn) portion of the curve, the gas from the 2-pt cylinder probably travels out farther. The 6-pt cylinder apparently is inferior to both the 2- and 4-pt systems. (This result does not mean that all 6-pt systems would be inferior, since detonator placement and timing affected the results.)

The 1-pt cylinder falls substantially below the 2- and 4-pt cylinders. It appears that the 6-pt cylinder may not project gases out any further than the 1-pt cylinder, even though the initial velocity is much higher. However, an extrapolation is made over too great a distance to give a reliable value for the limit.

The results in Fig. 8 show that, under comparable initiation, the velocities are higher for prisms than for cylinders. The U -vs- $X^{1/3}$ curves, though, are not linear, showing appreciable downward curvature. Analogous to the behavior of the cylinders, the gas velocity is initially higher for the 4-pt prism than for the 2-pt prism. As expected, the performance of the 1-pt prism falls well below that of the 2- and 4-pt prisms.

The distances (x) the gas front travels before stagnation occurs, derived from Figs. 7 and 8, are listed in Table 1. Also included are the distances (x) scaled up to correspond to 100-lb charges.

In Table 2 are given the instantaneous shock velocities (U_s) measured six feet from the actual size charge, the sphere excepted. Also given are the results scaled to 33.2 feet from a 100-lb charge. The peak over pressure (P_s) in the last column was obtained, except for the sphere, by conversion from the measured values of U_s (Nav. Ord. Report 2986, Fig. A12). The value given for the sphere was obtained using gages and larger charges (Denver Research Institute, Final Report, DRI 2286, Nov. 1965).

SUMMARY

The following observations and conclusions can be drawn from this study and the earlier work of others:

a) The contour of the charge surface is of fundamental importance in directing the gas motion. A flat surface produces more directionality of the gas flow than does a convex surface; a concave surface might produce even more. However, a concave surface with a short radius of curvature may cause the gas to converge too much, resulting in a rapid dispersion of the gas at greater distances;

b) The interaction of detonation waves can be made to greatly increase the outward gas velocity in certain directions. Head-on detonation-wave collisions in dual-end-initiated charges (1 detonator at each end) give rise to much higher lateral velocities than are obtained in corresponding single-end-initiated systems;

c) The use of additional points of initiation can significantly increase the initial gas velocity. However, this does not necessarily increase the total distance the gas will travel before stagnation occurs. The introduction of the proper amount of delay between detonators may improve the performance, but this has not been tried on the systems of Fig. 1;

d) The distance the gas travels before stagnation sets in can be deduced from U_s — vs $X^{1/3}$ plots, even though the stagnation is not observed;

e) The gas envelope does not tend to become more spherical as it expands. On the contrary, the envelope irregularities become more exaggerated, even to the point of gas stagnation. The air shock, however, rapidly takes on a spherical form after the product-gas motion stops. Though the relationship between gas stagnation and target damage remains to be determined, it is apparent that shock-wave degradation beyond the stagnation distance will be quite rapid since the gases formed the "piston" which produced the shock;

f) It appears that cube-root scaling holds for center-initiated spheres and single-end-initiated cylinders. It may hold for the other systems as well, but we will have to wait for large-scale results of comparable systems; and

g) If scaling does hold, none of the systems studies so far will project gas much beyond 40 feet from a 100-lb charge.

Table 1. Maximum distance, X_s, traveled by the leading edge of gaseous products of detonation in the "aimed" direction from various 0.57-lb. charge systems. [X_s' is the distance scaled to a 100-lb. charge.]

Shape of Charge	Mode of Initiation	X_s (feet)	X_s' (feet)
Sphere*	1 pt	2.5	14
Cylinder	1 pt	4	23
Cylinder	2 pt	5.5	32
Cylinder	4 pt	5.1	29
Cylinder	6 pt	4-5	23-29
Prism	1 pt	(to be determined)	
Prism	2 pt	6.3	36
Prism	4 pt	6-7	35-40

* 0.11-lb (50-g) charge scaled to 0.57-lb (260g)

Table 2. Instantaneous shock velocity, U_s, and overpressure, P_s, at a scaled distance of 33.2 feet from a 100-lb charge.

Shape of Charge	Mode of Initiation	U_s (m/sec)	U_s (ft/sec)	P_s (PSI)
Sphere	1 pt	---	----	13*
Cylinder	1 pt	448	1470	14.5*
Cylinder	2 pt	469	1539	17 **
Cylinder	4 pt	528	1732	21 **
Cylinder	6 pt	442	1450	12 **
Prism	1 pt	(to be determined)		
Prism	2 pt	816	2677	80 **
Prism	4 pt	(to be determined)		

* Pressure gage value (Denver Research Inst.)

** NavOrd Report 2986, Fig. A12

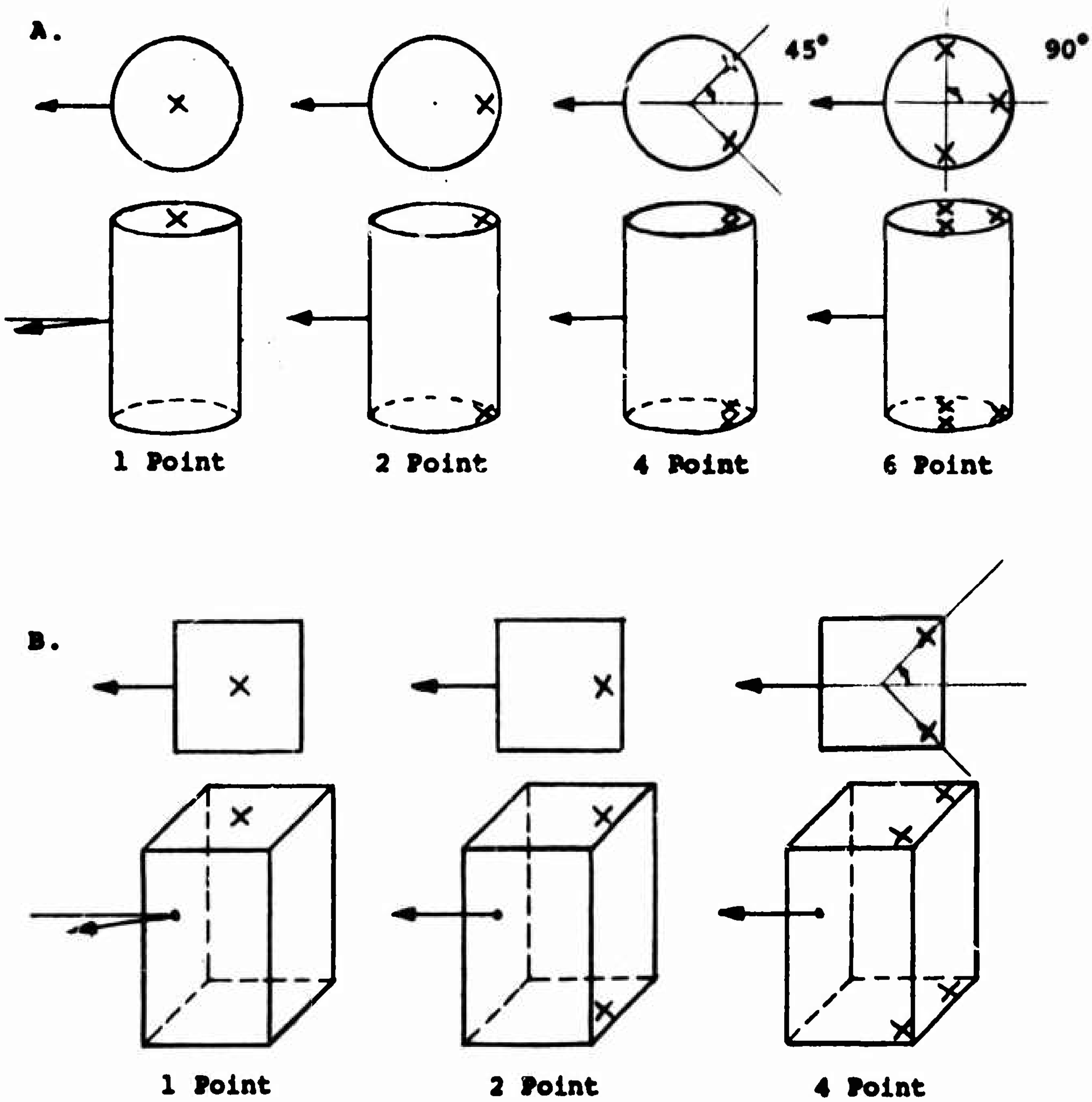

Fig. 1. Charge systems used in directed blast studies;
A. 257-g cylinders
B. 261-g square prisms
(Arrow points in direction of velocity measurement.)

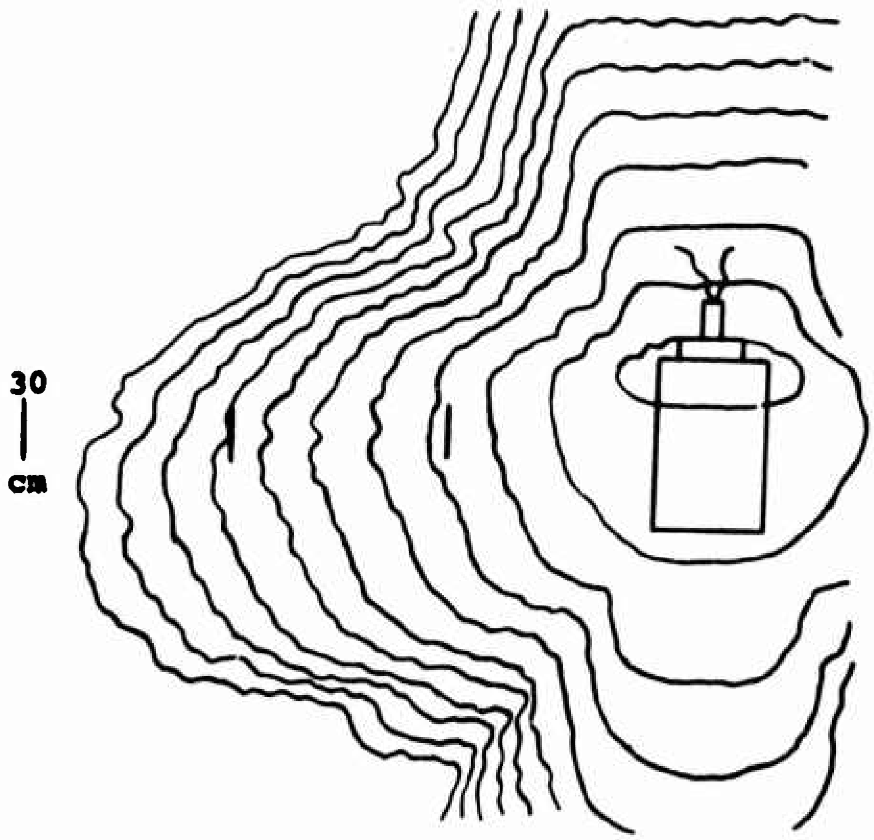

Fig 2. Expanding gas profiles from a one-point-initiated cylinder. (6.53 μsec between outlines).

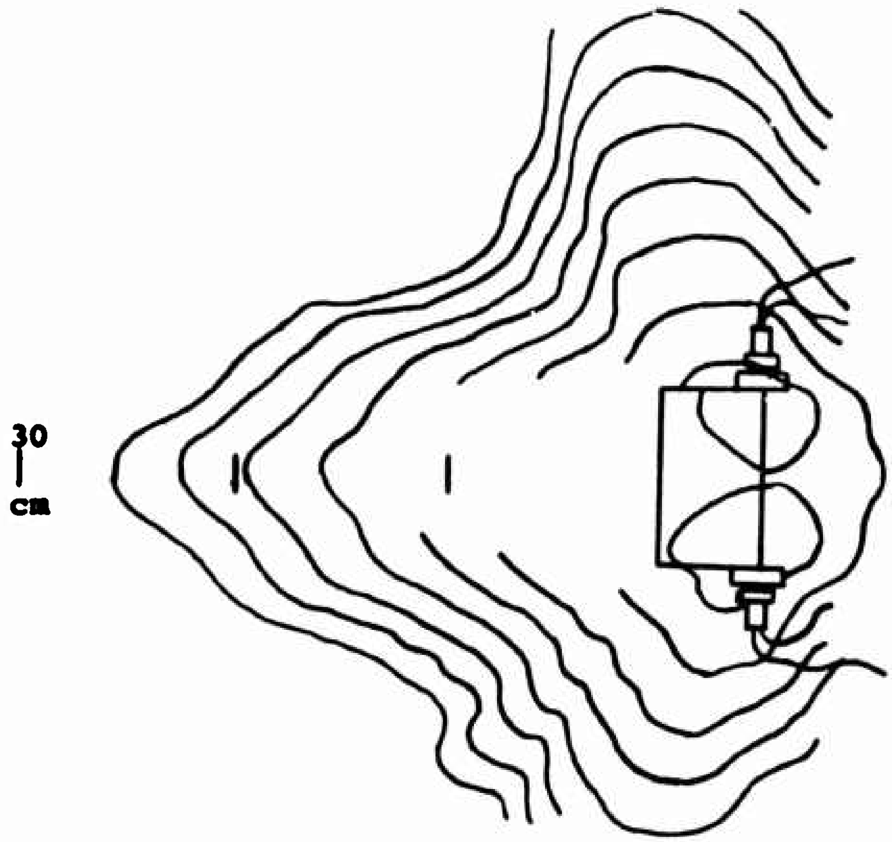

Fig. 3. Expanding gas profiles from a two-point-initiated cylinder. (6.53 μsec between outlines).

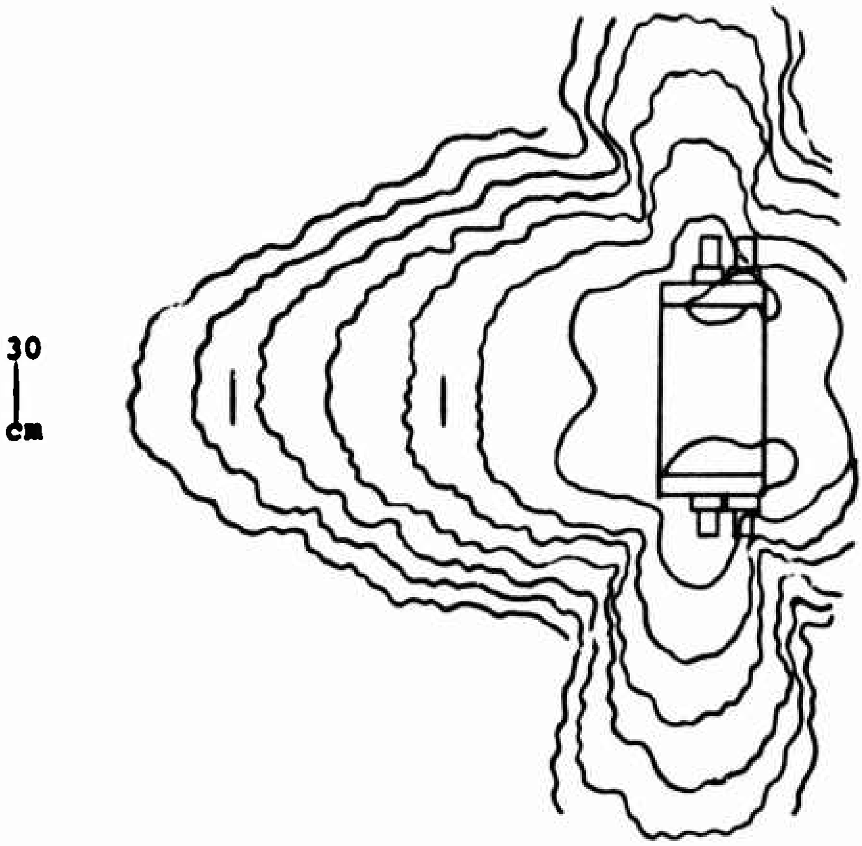

Fig. 4. Expanding gas profiles form a six-point-initiated cylinder. (6.53 μsec between outlines).

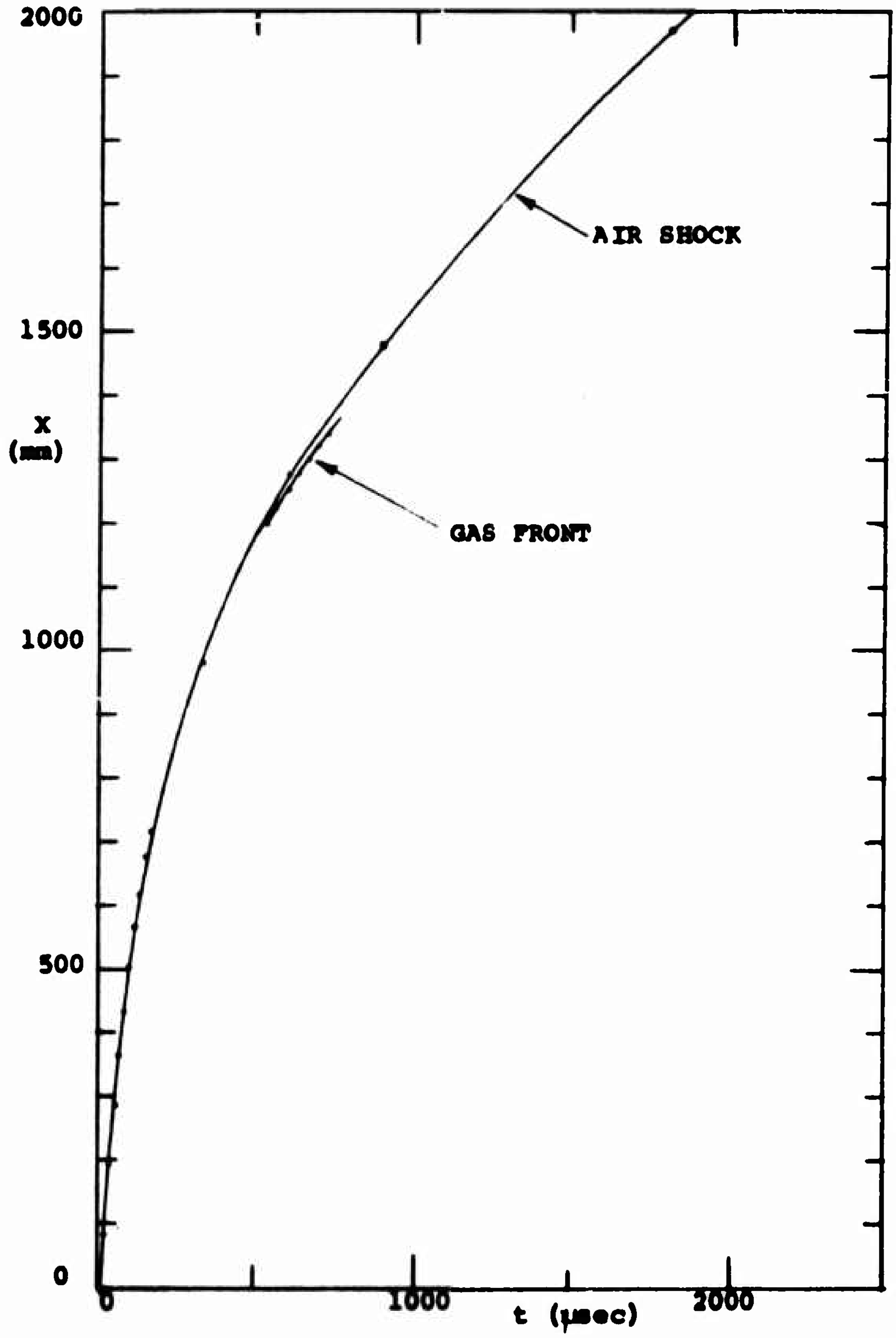

Fig. 5. An x-t plot of the shock front from a 4-point cylinder.

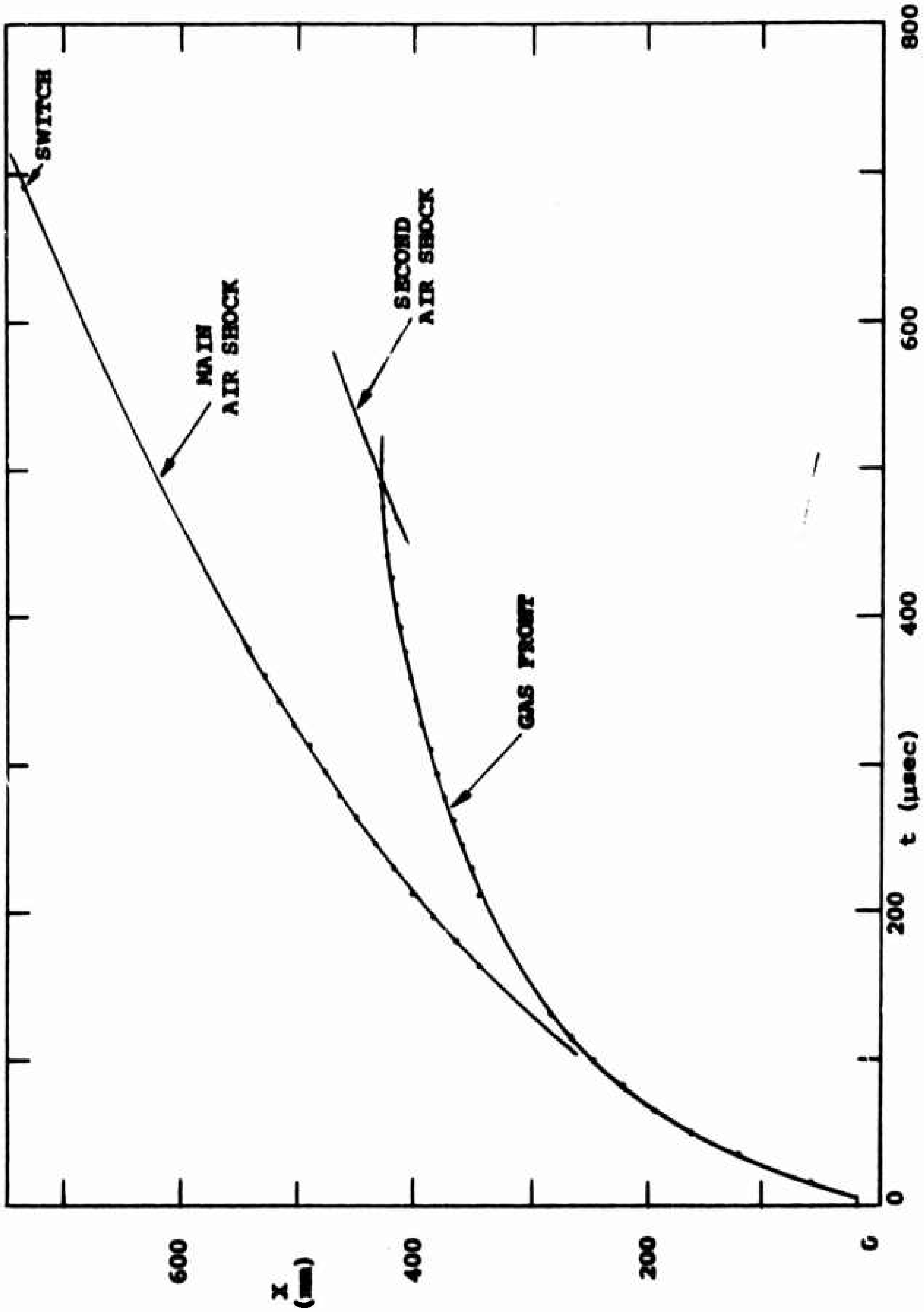

Fig 6. An x-t plot of the shock and gas front from a 50-g pentolite sphere.

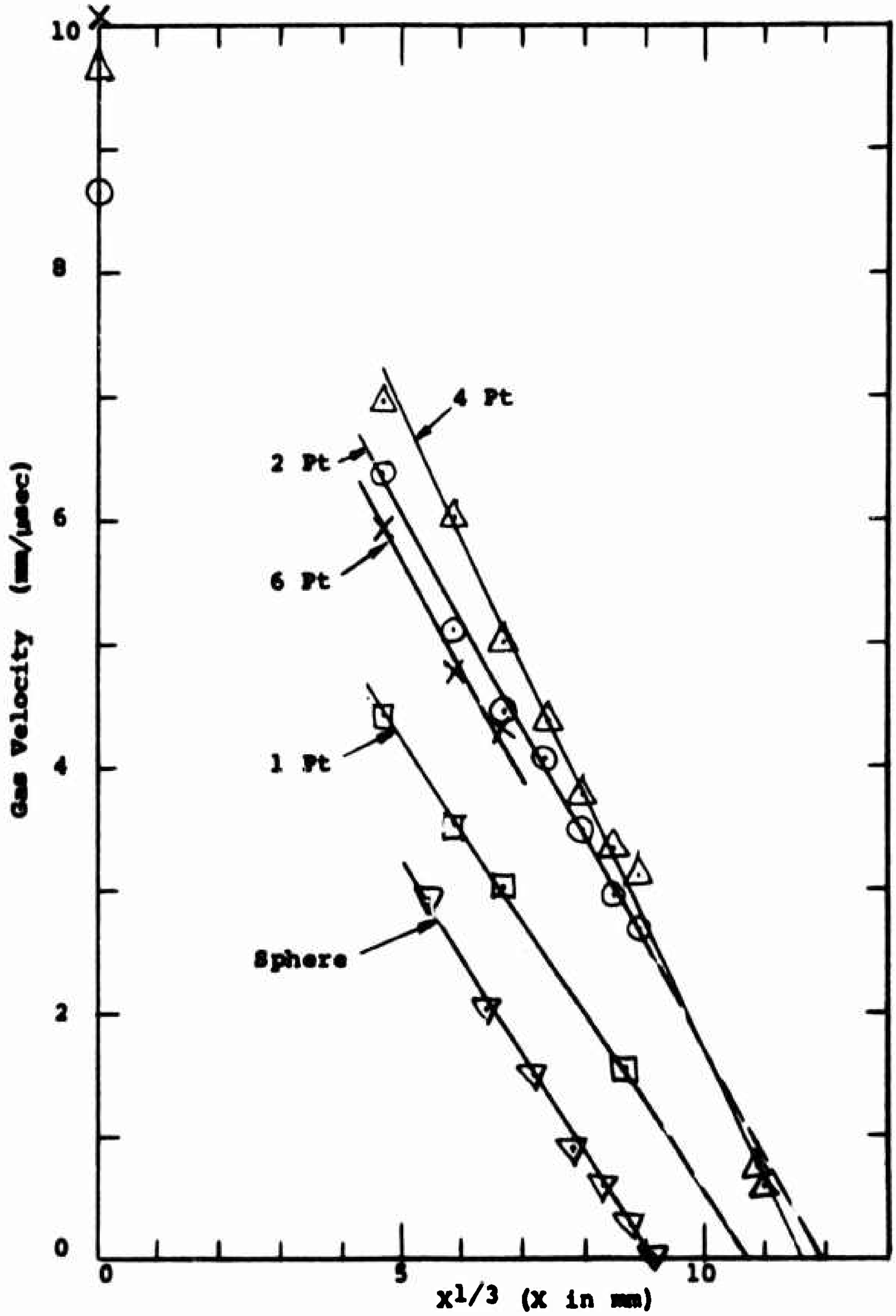

Fig. 7. Gas velocity vs $X^{1/3}$ for variously initiated cylinders. (Scaled results of the sphere also are given).

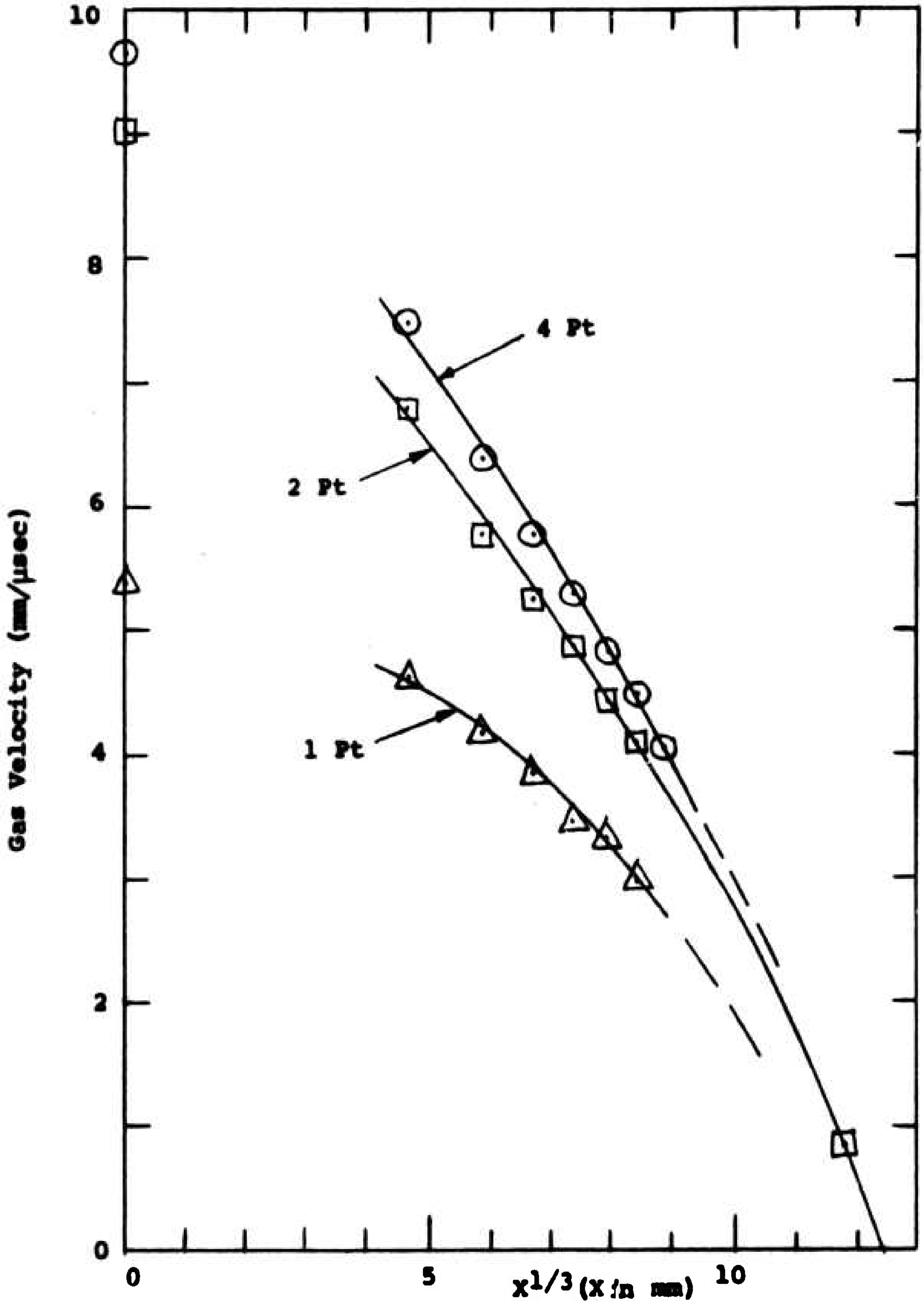

Fig. 8. Gas velocity vs $X^{1/3}$ for 1-, 2-, and 4-point-initiated square prisms.